1. INTRODUCTION

1.1. PURPOSE

The purpose of the Exposure Factors Handbook is to: (1) summarize data on human behaviors and characteristics which affect exposure to environmental contaminants, and (2) recommend values to use for these factors. These recommendations are not legally binding on any EPA program and should be interpreted as suggestions which program offices or individual exposure assessors can consider and modify as needed. Most of these factors are best quantified on a site or situation-specific basis. The Handbook has strived to include full discussions of the issues which assessors should consider in deciding how to use these data and recommendations. The Handbook is intended to serve as a support document to EPA's Guidelines for Exposure Assessment (U.S. EPA, 1992). The Guidelines were developed to promote consistency among the various exposure assessment activities that are carried out by the various EPA program offices. This handbook assists in this goal by providing a consistent set of exposure factors to calculate dose.

1.2. INTENDED AUDIENCE

The Exposure Factors Handbook is addressed to exposure assessors inside the Agency as well as outside, who need to obtain data on standard factors needed to calculate human exposure to toxic chemicals.

Purpose

- Summarize data on human behaviors and characteristics affecting exposure
- Recommend exposure factor values

1.3. BACKGROUND

This handbook is the update of an earlier version prepared in 1989. Revisions have been made in the following areas:

- addition of drinking water rates for children;
- changes in soil ingestion rates for children;
- addition of soil ingestion rates for adults;
- addition of tapwater consumption for adults and children;
- addition of mean daily intake of food class and subclass by region, age and per capita rates;
- addition of mean moisture content of selected fruits, vegetables, grains, fish, meat, and dairy products;
- addition of food intake by class in dry weight per kg of body weight per day;
- update of homegrown food intake;
- expansion of data in the dermal chapter;
- update of fish intake data;
- expansion of data for time spent at residence;
- update of body weight data;
- update of population mobility data;
- addition of new data for average time spent in different locations and various microenvironments;
- addition of data for occupational mobility;
- addition of breast milk ingestion;
- addition of consumer product use; and
- addition of reference residence factors.

Variation Among Studies

This handbook is a compilation of available data from a variety of different sources. With very few exceptions, the data presented are the analyses of the individual study authors. Since the studies included in this handbook varied in terms of their objectives, design, scope, presentation of results, etc., the level of detail, statistics, and terminology may vary from study to study and from factor to factor. For example, some authors used geometric means to present their results, while others used arithmetic means or distributions. Authors have sometimes used different terms to describe the same racial populations. Within the constraint of presenting the original material as accurately as possible, EPA has made an effort to present discussions and results in a consistent manner. Further, the strengths and limitations of each study are discussed to provide the reader with a better understanding of the uncertainties associated with the values derived from the study.

1.3.1. Selection of Studies for the Handbook

Information in this handbook has been summarized from studies documented in the scientific literature and other available sources. Studies were chosen that were seen as useful and appropriate for estimating exposure factors.

General Considerations

Many scientific studies were reviewed for possible inclusion in this handbook. Studies were selected based on the following considerations:

- Level of peer review: Studies were selected predominantly from the peer-reviewed literature and final government reports. Internal or interim reports were therefore avoided.

- Accessibility: Studies were preferred that the user could access in their entirety if needed.

- Reproducibility: Studies were sought that contained sufficient information so that methods could be reproduced, or at least so the details of the author's work could be accessed and evaluated.

- Focus on exposure factor of interest: Studies were chosen that directly addressed the exposure factor of interest, or addressed related factors that have significance for the factor under consideration. As an example of the latter case, a selected study contained useful ancillary information concerning fat content in fish, although it did not directly address fish consumption.

- Data pertinent to the U.S.: Studies were selected that addressed the U.S. population. Data from populations outside the U.S. were sometimes included if behavioral patterns and other characteristics of exposure were similar.

- Primary data: Studies were deemed preferable if based on primary data, but studies based on secondary sources were also included where they offered an original analysis. For example, the Handbook cites studies of food consumption based on original data collected by the USDA National Food Consumption Survey.

- Current information: Studies were chosen only if they were sufficiently recent to represent current exposure conditions. This is an important consideration for those factors that change with time.

- Adequacy of data collection period: Because most users of the Handbook are primarily addressing chronic exposures, studies were sought that utilized the most appropriate techniques for collecting data to characterize long-term behavior.

- Validity of approach: Studies utilizing experimental procedures or approaches that more likely or closely capture the desired measurement were selected. In general, direct exposure data collection techniques, such as direct observation, personal monitoring devices, or other known methods were preferred where available. If studies utilizing direct measurement were not available, studies were selected that rely on validated indirect measurement methods such as surrogate measures (such as heart rate for inhalation rate), and use of questionnaires. If questionnaires or surveys were used, proper design and procedures include an adequate sample size for the population under consideration, a response rate large enough to avoid biases, and avoidance of bias in the design of the instrument and interpretation of the results.

- Representativeness of the population: Studies seeking to characterize the national population, a particular region, or sub-population were selected, if appropriately representative of that population. In cases where data were limited, studies with limitations in this area were included and limitations were noted in the handbook.

- Variability in the population: Studies were sought that characterized any variability within populations.

- Minimal (or defined) bias in study design: Studies were sought that were designed with minimal bias, or at least if biases were suspected to be present, the direction of the bias (i.e. an over or under estimate of the parameter) was either stated or apparent from the study design.

- Minimal (or defined) uncertainty in the data: Studies were sought with minimal uncertainty in the data, which was judged by evaluating all the considerations listed above. At least, studies were preferred that identified

uncertainties, such as those due to inherent variability in environmental and exposure-related parameters or possible measurement error. Studies that documented Quality Assurance/Quality Control measures were preferable.

Key versus relevant studies

Certain studies described in this handbook are designated as "key," that is, the most useful for deriving exposure factors. The recommended values for most exposure factors are based on the results of the key studies. Other studies are designated "relevant," meaning applicable or pertinent, but not necessarily the most important. This distinction was made on the strength of the attributes listed in the "General Considerations." For example, in Chapter 14 of Volume III, one set of studies is deemed to best address the attributes listed and is designated as "key." Other applicable studies, including foreign data, believed to have value to Handbook users, but having fewer attributes, are designated "relevant."

1.3.2. Using the Handbook in an Exposure Assessment

Some of the steps for performing an exposure assessment are (1) determining the pathways of exposure, (2) identifying the environmental media which transports the contaminant, (3) determining the contaminant concentration, (4) determining the exposure time, frequency, and duration, and (5) identifying the exposed population. Many of the issues related to characterizing exposure from selected exposure pathways have been addressed in a number of existing EPA guidance documents. These include, but are not limited to the following:

- Guidelines for Exposure Assessment (U.S. EPA 1992a);
- Dermal Exposure Assessment: Principles and Applications (U.S. EPA 1992b);
- Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustion Emissions (U.S. EPA, 1990);
- Risk Assessment Guidance for Superfund (U.S. EPA, 1989);
- Estimating Exposures to Dioxin-Like Compounds (U.S. EPA, 1994);
- Superfund Exposure Assessment Manual (U.S. EPA, 1988a);
- Selection Criteria for Models Used in Exposure Assessments (U.S. EPA 1988b);
- Selection Criteria for Mathematical Models Used in Exposure Assessments (U.S. EPA 1987);
- Standard Scenarios for Estimating Exposure to Chemical Substances During Use of Consumer Products (U.S. EPA 1986a);
- Pesticide Assessment Guidelines, Subdivisions K and U (U.S. EPA, 1984, 1986b); and
- Methods for Assessing Exposure to Chemical Substances, Volumes 1-13 (U.S. EPA, 1983-1989).

These documents may serve as valuable information resources to assist in the assessment of exposure. The reader is encouraged to refer to them for more detailed discussion.

Key vs. Relevant Studies

- Key studies used to derive recommendations
- Relevant studies included to provide additional perspective

In addition to the references listed above, this handbook discusses the recommendations provided by the American Industrial Health Council (AIHC) - Exposure Factors Sourcebook (May 1994) for some of the major exposure factors. The AIHC Sourcebook summarizes and evaluates statistical data for various exposure factors used in risk assessments. Probability distributions for specific exposure factors were derived from the available scientific literature using @Risk simulation software. Each factor is described by a specific term, such as lognormal, normal, cumulative type, or triangular. Other distributions included Weibull, beta logistic, and gamma. Unlike this handbook, however, the Sourcebook does not provide a description and evaluation of every study available on each exposure factor.

Due to unique activity patterns, preferences, practices and biological differences, various segments of the population may experience exposures different from those of the general population, which, in many cases,

may be greater. It is necessary for risk or exposure assessors characterizing a diverse population, to identify and enumerate certain groups within the general population who are at risk for greater contaminant exposures or exhibit a heightened sensitivity to particular chemicals. For further guidance on addressing susceptible populations, it is recommended to consult the EPA, National Center for Environmental Assessment document *Socio-demographic Data Used for Identifying Potentially Highly Exposed Subpopulations* (to be released as a final document December 1996).

Most users of the Handbook will be preparing estimates of exposure which are to be combined with dose-response factors to estimate risk. Some of the exposure factors (e.g., life time, body weight) presented in this document are also used in generating dose-response relationships. In order to develop risk estimates properly, assessors must use dose-response relationships in a manner consistent with exposure conditions. Although, it is beyond the scope of this document to explain in detail how assessors should address this issue, a discussion (see Appendix A of this chapter) has been included which describes how dose-response factors can be modified to be consistent with the exposure factors for a population of interest. This should serve as a guide for when this issue is a concern.

Recommendations and Confidence Ratings

- Recommendations based on data from single or multiple key studies
- Variability and uncertainty of recommended values evaluated
- Factors rated as low, medium, and high confidence

1.3.3. Approach Used to Develop Recommendations for Exposure Factors

As discussed above, EPA first reviewed all literature pertaining to a factor and determined relevant and key studies. The key studies were used to derive recommendations for the values of each factor. The recommended values were derived solely from EPA's interpretation of the available data. Different values may be appropriate for the user to select in consideration of policy, precedent, strategy, or other factors such as site-specific information. EPA's procedure for developing recommendations was as follows:

1. Key studies were evaluated in terms of both quality and relevance to specific populations (general U. S. population, age groups, gender, etc). The criteria for assessing the quality of studies is described in Section 1.3.1.

2. If only one study has been classified as key for a particular factor, the mean value from that study is selected as the recommended central value for that population. If there are multiple key studies, all with reasonably equal quality, relevance and study design are available, a weighted mean (if appropriate, considering sample size and other statistical factors) of the studies was chosen as the recommended mean value. If the key studies were judged to be unequal in quality, relevance, or study design, the range of means are presented and the user of this handbook must employ judgment in selecting the most appropriate value for the population of interest. In cases where the national population is of interest, the mid-point of the range would usually be judged to be the most appropriate value.

3. The variability of the factor across the population was discussed. If adequate data were available, the variability is described as either a series of percentiles or a distribution.

4. The uncertainty in each recommended value was discussed in terms of data limitations, the range of circumstances over which the estimates are (or are not) applicable, possible biases in the values themselves, a statement about parameter uncertainties (measurement error, sampling error) and model or scenario uncertainties if models or scenarios have been used in the derivation of the recommended value.

5. Finally, EPA assigned a confidence rating of low, medium or high to each recommended value. This rating is based on judgment using the guidelines shown in Table 1-1. Table 1-1 is an adaptation of the General Considerations discussed earlier in Section 1.3.1. Clearly this is a continuum from low to high and judgment was used to determine these ratings. Recommendations given in this handbook are accompanied by a discussion of the rationale for their rating.

Table 1-2 summarizes EPA's recommendations and confidence ratings for the various exposure factors.

1.3.4. Characterizing Variability

This document attempts to characterize variability of each of the factors. Variability is characterized in one or more of three ways: (1) as tables with various percentiles or ranges of values; (2) as analytical distributions with specified parameters; and/or (3) as a qualitative discussion. Analyses to fit standard or parametric distributions (e.g., normal, lognormal) to the exposure data have not been performed by the authors of this handbook, but have been reproduced in this document wherever they were found in the literature. Recommendations on the use of these distributions are made where appropriate based on the adequacy of the supporting data. The list of exposure factors and the way that variability has been characterized (i.e., average, upper percentiles, multiple percentiles, fitted distribution) are presented in Table 1-3.

The use of Monte Carlo or other probabilistic analysis require a selection of distributions or histograms for the input parameters. Although this handbook is not intended to provide a complete guidance on the use of Monte Carlo and other probabilistic analyses, the following should be considered when using such techniques:

- The exposure assessor should only consider using probabilistic analysis when there are credible distribution data (or ranges) for the factor under consideration. Even if these distributions are known, it may not be necessary to apply this technique. For example, if only average exposure values are needed, these can often be computed accurately by using average values for each of the input parameters. Probabilistic analysis is also not necessary when conducting assessments for screening purposes, i.e, to determine if unimportant pathways can be eliminated. In this case, bounding estimates can be calculated using maximum or near maximum values for each of the input parameters.

- It is important to note that the selection of distributions can be highly site specific and will always involve some degree of judgment. Distributions derived from national data may

not represent local conditions. To the extent possible, an assessor should use distributions or frequency histograms derived from local surveys to assess risks locally. When distributional data are drawn from national or other surrogate population, it is important that the assessor address the extent to which local conditions may differ from the surrogate data. In addition to a qualitative statement of uncertainty, the representativeness assumption should be appropriately addressed as part of a sensitivity analysis.

- Distribution functions to be used in Monte Carlo analysis may be derived by fitting an appropriate function to empirical data. In doing this, it should be recognized that in the lower and upper tails of the distribution the data are scarce, so that several functions, with radically different shapes in the extreme tails, may be consistent with the data. To avoid introducing errors into the analysis by the arbitrary choice of an inappropriate function, several techniques can be used. One way is to avoid the problem by using the empirical data itself rather than an analytic function. Another is to do separate analyses with several functions which have adequate fit but form upper and lower bounds to the empirical data. A third way is to use truncated analytical distributions. Judgment must be used in choosing the appropriate goodness of fit test. Information on the theoretical basis for fitting distributions can be found in a standard statistics text such as Statistical Methods for Environmental Pollution Monitoring, Gilbert, R.O., 1987, Van Nostrand Reinhold; off-the-shelf computer software such as Best-Fit by Palisade Corporation can be used to

Table 1-1. Considerations Used to Rate Confidence in Recommended Values

CONSIDERATIONS	HIGH CONFIDENCE	LOW CONFIDENCE
Study Elements		
Level of peer review	Studies received high level of peer review (e.g., they appear in peer review journals)	Studies received limited peer review
Accessibility	Studies are widely available to the public	Studies are difficult to obtain (e.g., draft reports, unpublished data)
Reproducibility	Results can be reproduced or methodology can be followed and evaluated	Results cannot be reproduced, methodology is hard to follow, and author(s) cannot be located
Focus on factor of interest	Studies focused on the exposure factor of interest	Purpose of the studies were to characterize a related factor
Data pertinent to U.S.	Studies focused on the U.S. population	Studies focused on populations outside the U.S.
Primary data	Studies analyzed primary data	Studies are based on secondary sources
Currency	After 1990	Before 1980
Adequacy of data collection period	Study design captures the measurement of interest (e.g., usual consumption patterns of a population)	Study design does not very accurately captures the measurement of interest
Validity of approach	Studies used the best methodology available to capture the measurement of interest	There are serious limitations with the approach used
Study sizes	n > 100	n < 20
	The sample size depends on how the target population is defined. As the size of a sample relative to the total size of the target population increases, estimates are made with greater statistical assurance that the sample results reflect actual characteristics of the target population.	
Representativeness of the population	Study population same as population of interest	Study population very different from the population of interest
Variability in the population	Studies characterized variability in the population studied	Characterization of variability is limited
Lack of bias in study design (a high rating is desirable)	Potential bias in the studies are stated or can be determined from study design	Study design introduces biases in the results
Response rates		< 40%
In-person interviews	> 80%	< 40%
Telephone interviews	> 80%	< 40%
Mail surveys	> 70%	
Measurement error	Study design minimizes measurement errors	Uncertainties with the data exists due to measurement error
Other Elements		
Number of studies	> 3	1
Agreement between researchers	Results of studies from different researchers are in agreement	Results of studies from different researchers are in disagreement

[a] Differences include age, sex, race, income, or other demographic parameters.

Table 1-2. Summary of Exposure Factor Recommendations and Confidence Ratings

EXPOSURE FACTOR	RECOMMENDATION	CONFIDENCE RATING
Drinking water intake rate	21 ml/kg-day (average) 34 ml/kg-day (90th percentile) Percentiles and distribution also included	Medium
Total fruit intake rate	3.4 g/kg-day (average) 12.4 g/kg-day (95th percentile) Percentiles also included Means presented for individual fruits	Medium Low
Total vegetable intake rate	4.3 g/kg-day (average) 10 g/kg-day (95th percentile) Percentiles also included Means presented for individual vegetables	Medium Low
Total meat intake rate	2.1 g/kg-day (average) 5.1 g/kg-day (95th percentile) Percentiles also included Means presented for individual meats	Medium Low
Total dairy intake rate	8.0 g/kg-day (average) 29.7 g/kg-day (95th percentile) Percentiles also included Means presented for individual dairy products	Medium Low
Breast milk intake rate	742 ml/day (average) 1,033 ml/day (upper percentile)	Medium Medium
Fish intake rate	General Population 20.1 g/day (total fish) average 13.5 g/day (marine) average 6.6 g/day (freshwater/estuarine)average 63 g/day (total fish)95th percentile long-term Serving size 123 g (average) 305 g (95th percentile) Recreational marine anglers 2 - 7 g/day (finfish only) Recreational freshwater 8 g/day (average) 25 g/day (95th percentile) Native American Subsistence Population 70 g/day (average) 170 g/day (95th percentile)	 Medium Medium Medium Medium High High Medium Medium Medium Medium Low
Home produced food intake	Total Fruits 2.7 g/kg-day (average) 11.1 g/kg-day (95th percentile) Total vegetables 2.1 g/kg-day (average) 7.5 g/kg-day (95th percentile) Total meats 2.2 g/kg-day (average) 6.8 g/kg-day (95th percentile) Total dairy products 14 g/kg-day (average) 44 g/kg-day (95th percentile) Percentiles also included Means presented for individual food items	Medium (for means and short-term distributions) Low (for long-term distributions)

Table 1-2. Summary of Exposure Factor Recommendations and Confidence Ratings (continued)

EXPOSURE FACTOR	RECOMMENDATION	CONFIDENCE RATING
Inhalation rate	Children (< 1 year) 4.5 m^3/day (average) Children (1-12 years) 8.7 m^3/day (average) Adult Females 11.3 m^3/day (average) Adult Males 15.2 m^3/day (average)	 High High High High
Surface area	Water contact (bathing and swimming) Use total body surface area for children in Tables 6-6 through 6-8; for adults use Tables 6-2 through 6-4 (percentiles are included) Soil contact (outdoor activities) Use whole body part area based on Table 6-6 through 6-8 for children and 6-2 through 6-4 for adults (percentiles are included)	 High
Soil adherence	Use values presented in Table 6-16 depending on activity and body part (central estimates only)	Low
Soil ingestion rate	Children 100 mg/day (average) 400 mg/day (upper percentile) Adults 50 mg/day (average) Pica child 10 g/day	 Medium Low Low
Life expectancy	75 years	High
Body weight	71.8 kg	High
Showering/Bathing	Showering time 8 min/day (average) 12 min/day (95th percentile) (percentiles are also included) Bathing time 20 min/event (median) 45 min/event (90th percentile) Bathing/showering frequency 1 shower event/day	 Medium High High
Swimming	Frequency 1 event/month Duration 60 min/event (median) 180 min/event (90th percentile)	 High High
Time indoors	Children (ages 3-11) 19 hr/day (weekdays) 17 hr/day (weekends) Adults (ages 12 and older) 21 hr/day Residential 16.4 hrs/day	Medium Medium High
Time outdoors	Children (ages 3-11) 5 hr/day (weekdays) 7 hr/day (weekends) Adults 1.5 hr/day Residential 2 hrs/day	Medium Medium High

Table 1-2. Summary of Exposure Factor Recommendations and Confidence Ratings (continued)

EXPOSURE FACTOR	RECOMMENDATION	CONFIDENCE RATING
Time spent inside vehicle	Adults 1 hr 20 min/day	Medium
Occupational tenure	6.6 years (16 years old and older)	High
Population mobility	9 years (average) 30 years (95th percentile)	Medium
Residence volume	369 m^3 (average) 217 m^3 (conservative)	Medium
Residential air exchange	0.45 (median) 0.18 (conservative)	Medium

Table 1-3. Characterization of Variability in Exposure Factors

Exposure Factors	Average	Upper percentile	Multiple Percentiles	Fitted Distributions
Drinking water intake rate	✓	✓	✓	✓
Total fruits and total vegetables intake rate	✓	✓ Qualitative discussion for long-term	✓	
Individual fruits and individual vegetables intake rate	✓			
Total meats and dairy products intake rate	✓	✓ Qualitative discussion for long-term	✓	
Individual meats and dairy products intake rate	✓			
Serving size for various food items	✓	✓	✓	
Breast milk intake rate	✓	✓		
Fish intake rate for general population, recreational marine, recreational freshwater, and native american	✓	✓		
Homeproduced food intake rates	✓	✓ Only provided for the total groups (i.e., total fruits, total vegetables and total meats and dairy)	✓ Long-term values only for the total groups (i.e., total fruits, total vegetables and total meats and dairy)	
Soil intake rate	✓	Qualitative discussion for long-term		
Inhalation rate	✓	✓		
Surface area	✓	✓	✓	
Soil adherence	✓			
Life expectancy	✓			
Body weight	✓	✓	✓	
Time indoors	✓			
Time outdoors	✓			
Showering time	✓	✓	✓	
Occupational tenure	✓			
Population mobility	✓	✓	✓	

statistically determine the distributions that fit the data.

- If only a range of values is known for an exposure factor, the assessor has several options.

  - keep that variable constant at its central value;
  - assume several values within the range of values for the exposure factor;
  - calculate a point estimate(s) instead of using probabilistic analysis; and
  - assume a distribution (The rationale for the selection of a distribution should be discussed at length.) There are, however, cases where assuming a distribution is not recommended. These include:

    -- data are missing or very limited for a key parameter - Examples include: soil ingestion by adults;
    -- data were collected over a short time period and may not represent long term trends (the respondent usual behavior). Examples include: food consumption surveys; activity pattern data;
    -- data are not representative of the population of interest because sample size was small or the population studied was selected from a local area and therefore not representative of the area of interest - Examples include: soil ingestion by children; and
    -- ranges for a key variable are uncertain due to experimental error or other limitations in the study design or methodology- Examples include: soil ingestion by children.

1.4. GENERAL EQUATION FOR CALCULATING DOSE

The definition of exposure as used in the Exposure Guidelines (U.S. EPA, 1992a) is "condition of a chemical contacting the outer boundary of a human." This means contact with the visible exterior of a person such as the skin, and openings such as the mouth, nostrils, and lesions. The process of a chemical entering the body can be described in two steps: contact (exposure), followed by entry (crossing the boundary). The magnitude of exposure (dose) is the amount of agent available at human exchange boundaries (skin, lungs, gut) where absorption takes place during some specified time. Starting with a general integral equation for exposure (U.S. EPA 1992a), several dose equations can be derived depending upon boundary assumptions. One of the more useful of these derived equations is the Average Daily Dose (ADD). The ADD, which is used for many noncancer effects, averages exposures or doses over the period of time over which exposure occurred. The ADD can be calculated by averaging the potential dose (D_{pot}) over body weight and an averaging time.

$$ADD_{pot} = \frac{\text{Total Potential Dose}}{\text{Body Weight x Averaging Time}} \qquad \text{(Eqn. 1-1)}$$

For cancer effects, where the biological response is usually described in terms of lifetime probabilities, even though exposure does not occur over the entire lifetime, doses are often presented as lifetime average daily doses (LADDs). The LADD takes the form of the Equation 1-1 with lifetime replacing averaging time. The LADD is a very common term used in carcinogen risk assessment where linear non-threshold models are employed.

The total exposure can be expressed as follows:

$$\text{Total Potential Dose} = CC \times IR \times ED \qquad \text{(Eqn. 1-2)}$$

Where:

CC = Contaminant Concentration

Contaminant concentration is the concentration of the contaminant in the medium (air, food, soil, etc.) contacting the body and has units of mass/volume or mass/mass.

The intake rate refers to the rates of inhalation, ingestion, and dermal contact depending on the route of exposure. For ingestion, the intake rate is simply the amount of food containing the contaminant of interest that an individual ingests during some specific time period

(units of mass/time). Much of this handbook is devoted to rates of ingestion for some broad classes of food. For inhalation, the intake rate is the rate at which contaminated air is inhaled. Factors that affect dermal exposure are the amount of material that comes into contact with the skin, and the rate at which the contaminant is absorbed.

The exposure duration is the length of time that contaminant contact lasts. The time a person lives in an area, frequency of bathing, time spent indoors versus outdoors, etc. all affect the exposure duration. The Activity Factors Chapter (Volume III, Chapter 2) gives some examples of population behavior patterns, which may be useful for estimating exposure durations to be used in the exposure calculations.

When the above parameter values remain constant over time, they are substituted directly into the exposure equation. When they change with time, a summation approach is needed to calculate exposure. In either case, the exposure duration is the length of time exposure occurs at the concentration and intake rate specified by the other parameters in the equation.

Exposure can be expressed as a total amount (with units of mass, e.g., mg) or as an exposure rate in terms of mass/time (e.g., mg/day), or as a rate normalized to body mass (e.g., with units of mg of chemical per kg of body weight per day (mg/kg-day)). The LADD is usually expressed in terms of mg/kg-day or other mass/mass-time units.

In most cases (inhalation and ingestion exposure) the dose-response parameters for carcinogen risks have been adjusted for the difference in absorption across body barriers between humans and the experimental animals used to derive such parameters. Therefore, the exposure assessment in these cases is based on the potential dose with no explicit correction for the fraction absorbed. However, the exposure assessor needs to make such an adjustment when calculating dermal exposure and in other specific cases when current information indicates that the human absorption factor used in the derivation of the dose-response factor is inappropriate.

The lifetime value used in the LADD version of Equation 1-1 is the period of time over which the dose is averaged. For carcinogens, the derivation of the dose-response parameters usually assumes no explicit number of years as the duration of a lifetime, and the nominal value of 75 years is considered a reasonable approximation. For exposure estimates to be used for assessments other than carcinogenic risk, various averaging periods have been used. For acute exposures, the administered doses are usually averaged over a day or a single event. For nonchronic noncancer effects, the time period used is the actual period of exposure. The objective in selecting the exposure averaging time is to express the exposure in a way which can be combined with the dose-response relationship to calculate risk.

The body weight to be used in the exposure Equation (1-1) depends on the units of the exposure data presented in this handbook. For food ingestion, the body weights of the surveyed populations were known in the USDA surveys and they were explicitly factored into the food intake data in order to calculate the intake as grams per day per kilogram body weight. In this case, the body weight has already been included in the "intake rate" term in Equation (1-2) and the exposure assessor does not need to explicitly include body weight.

The units of intake in this handbook for the ingestion of fish, breast milk, and the inhalation of air are not normalized to body weight. In this case, the exposure assessor needs to use (in Equation 1-1) the average weight of the exposed population during the time when the exposure actually occurs. If the exposure occurs continuously throughout an individual's life or only during the adult ages, using an adult weight of 71.8 kg should provide sufficient accuracy. If the body weight of the individuals in the population whose risk is being evaluated is non-standard in some way, such as for children or for first-generation immigrants who may be smaller than the national population, and if reasonable values are not available in the literature, then a model of intake as a function of body weight must be used. One such model is discussed in Appendix 1A of this chapter. Some of the parameters (primarily concentrations) used in estimating exposure are exclusively site specific, and therefore default recommendations could not be used.

The link between the intake rate value and the exposure duration value is a common source of confusion in defining exposure scenarios. It is important to define the duration estimate so that it is consistent with the intake rate:

- The intake rate can be based on an individual event, such as 123 g of fish eaten per meal (Pao et al., 1982; CSFII, 1989-91). The duration should be based on the number of events or, in this case, meals.

- The intake rate also can be based on a long-term average, such as 10 g/day. In this case the duration should be based on the total time interval over which the exposure occurs.

The objective is to define the terms so that when multiplied, they give the appropriate estimate of mass of contaminant contacted. This can be accomplished by basing the intake rate on either a long-term average (chronic exposure) or an event (acute exposure) basis, as long as the duration value is selected appropriately. Consider the case in which a person eats a 123-g fish meal approximately five times per month (long-term average is 20 g/day) for 30 years; or 20 g/day of fish every day for 30 years.

(123 g/meal)(5 meals/mo)(mo/30 d)(365 d/yr)(30 yrs) = 219,000 g

(20 g/day)(365 d/yr)(30 yrs) = 219,000 g

Thus, a frequency of either 36.5 meals/year or a duration of 365 days/year could be used as long as it is matched with the appropriate intake rate.

1.5. RESEARCH NEEDS

In an earlier draft of this Handbook, reviewers were asked to identify factors or areas where further research is needed. The following list is a compilation of areas for future research identified by the peer reviewers and authors of this document:

- The data and information available with respect to occupational exposures are quite limited. Efforts need to be directed to identify data or references on occupational exposure.

- Further research is necessary to refine estimates of fish consumption, particularly by subpopulations of subsistence fishermen.

- Research is needed to better estimate soil intake rates, particularly how to extrapolate short-term data to chronic exposures. Data on soil intake rates by adults are very limited. Research in this area is also recommended. Research is also needed to refine methods to calculate soil intake rate (i.e., inconsistencies among tracers and input/output misalignment errors indicate a fundamental problem with the methods).

- In cases where several studies of equal quality and data collection procedures are available for an exposure factor, procedures need to be developed to combine the data in order to create a single distribution of likely values for that factor.

- Reviewers recommended that the Handbook be made available in CD ROM and that the data presented be made available in a format that will allow the users to conduct their own analysis. The intent is to provide a comprehensive factors tool with interactive menu to guide users to areas of interest, word searching features, and data base files.

- Reviewers recommended that EPA derive distribution functions using the empirical data for the various exposure factors to be used in Monte Carlo or other probabilistic analysis.

- Research is needed to derive a methodology to extrapolate from short-term data to long-term or chronic exposures.

- Reviewers recommended that the consumer products chapter be expanded to include more products. A comprehensive literature search needs to be conducted to investigate other sources of data.

1.6. ORGANIZATION

The Handbook is organized into three volumes as follows:

Volume I - General Factors

Chapter 1 — Provides the overall introduction to the Handbook

Chapter 2 — Presents an analysis of uncertainty and discusses methods that can be used to evaluate and present the uncertainty associated with exposure scenario estimates.

Chapter 3 — Provides factors for estimating human exposure through ingestion of water.

Chapter 4 — Provides factors for estimating exposure through ingestion of soil.

Chapter 5 Provides factors for estimating exposure as a result of inhalation of vapors and particulates.

Chapter 6 Presents factors for estimating dermal exposure to environmental contaminants that come in contact with the skin.

Chapter 7 Provides data on bodyweight.

Chapter 8 Provides data on life expectancy.

Volume II - Ingestion Factors

Chapter 9 Provides factors for estimating exposure through ingestion of fruits and vegetables.

Chapter 10 Provides factors for estimating exposure through ingestion of fish.

Chapter 11 Provides factors for estimating exposure through ingestion of meats and dairy products.

Chapter 12 Presents factors for estimating exposure through ingestion of home produced food.

Chapter 13 Presents data for estimating exposure through ingestion of breast milk.

Volume III - Activity Factors

Chapter 14 Presents data on activity factors (activity patterns, population mobility, and occupational mobility).

Chapter 15 Presents data on consumer product use.

Chapter 16 Presents factors used in estimating residential exposures.

Figure 1-1 provides a roadmap to assist users of this handbook in locating recommended values and confidence ratings for the various exposure factors presented in these chapters. A glossary is provided at the end of Volume III.

1.7. REFERENCES FOR CHAPTER 1

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APPENDIX 1A

RISK CALCULATIONS USING EXPOSURE HANDBOOK DATA AND DOSE-RESPONSE INFORMATION FROM THE INTEGRATED RISK INFORMATION SYSTEM (IRIS)

APPENDIX A
RISK CALCULATIONS USING EXPOSURE HANDBOOK DATA AND DOSE-RESPONSE INFORMATION FROM IRIS

1. INTRODUCTION

When calculating risk estimates for a specific population, whether the entire national population or some sub-population, the exposure information (either from this handbook or from other data) must be combined with dose-response information. The latter typically comes from the IRIS data base, which summarizes toxicity data for each agent separately. Care must be taken that the assumptions about population parameters in the dose-response analysis are consistent with the population parameters used in the exposure analysis. This Appendix discusses procedures for insuring this consistency.

In the IRIS derivation of threshold based dose-response relationships (U.S. EPA, 1996), such as the RfD and the RfCs based on adverse systemic effects, there has generally been no explicit use of human exposure factors. In these cases the numerical value of the RfD and RfC comes directly from animal dosing experiments (and occasionally from human studies) and from the application of uncertainty factors to reflect issues such as the duration of the experiment, the fact that animals are being used to represent humans and the quality of the study. However in developing cancer dose-response (D-R) assessments, a standard exposure scenario is assumed in calculating the slope factor (i.e. human cancer risk per unit dose) on the basis of either animal bioassay data or human data. This standard scenario has traditionally been assumed to be typical of the U.S. population: 1) body weight = 70 kg; 2) air intake rate = 20 m^3/day; 3) drinking water intake = 2 liters/day; 4) lifetime = 70 years. In RfC derivations for cases involving an adverse effect on the respiratory tract, the air intake rate of 20 m^3/day is assumed. The use of these specific values has depended on whether the slope factor was derived from animal or human epidemiologic data:

- Animal Data: For dose-resopnse (D-R) studies based on animal data scale animal doses to human equivalent doses using a human body weight assumption of 70 kg. No explicit lifetime adjustment is necessary because the assumption is made that events occurring in the lifetime animal bioassay will occur with equal probability in a human lifetime, whatever that might happen to be.

- Human Data - In the analysis of human studies (either occupational or general population) the Agency has usually made no explicit assumption of body weight or human lifetime. For both of these parameters there is an implicit assumption that the population usually of interest has the same descriptive parameters as the population analyzed by the Agency. In the rare situation where this assumption is known to be wrong, the Agency has made appropriate corrections so that the dose-response parameters represent the national average population.

When the population of interest is different than the national average (standard) population, the dose-response parameter needs to be adjusted. In addition, when the population of interest is different than the population from which the exposure factors in this handbook were derived, the exposure factor needs to be adjusted. Two generic examples of situations where these adjustments are needed are as follows:

. A) Detailed study of recent data, such as are presented in this handbook, show that EPA's standard assumptions (i.e., 70 kg body weight, 20 m^3/day air inhaled, and 2 L/day water intake) are inaccurate for the national population and may be inappropriate for sub-populations under consideration. The Handbook addresses most of these situations by providing gender- and age-specific values and by normalizing the intake values to body weight when the data are available, but it may not have covered all possible situations. An example of a sub-population with different mean body weight would be females, with an average body weight of 60 kg or children with a body weight dependent on age.

Another example of a non-standard sub-population would be a sedentary hospital population with lower than 20 m^3/day air intake rates.

B) The population variability of these parameters is of interest and it is desired to estimate percentile limits of the population variation. Although the detailed methods for estimating percentile limits of exposure and risk in a population are beyond the scope of this document, one would treat the body weight and the intake rates discussed in Sections 2 to 4 of this appendix as distributions, rather than constants.

2. CORRECTIONS FOR DOSE-RESPONSE PARAMETERS

The correction factors for the dose-response values tabulated in the IRIS data base for carcinogens are summarized in Table 1A-1. Use of these correction parameters is necessary to avoid introducing errors into the risk analysis. The second column of Table 1A-1 shows the dependencies that have been assumed in the typical situation where the human dose-response factors have been derived from the administered dose in animal studies. This table is applicable in most cases that will be encountered, but it is not applicable when: a) the effective dose has been derived with a pharmacokinetic model and b) the dose-response data has been derived from human data. In the former case, the subpopulation parameters need to be incorporated into the model. In the latter case the correction factor for the dose-response parameter must be evaluated on a case-by case basis by examining the specific data and assumptions in the derivation of the parameter.

Table 1A-1. Procedures for Modifying IRIS Risk Values for Non-standard Populations[a,b]

IRIS Risk Measure [Units]	IRIS Risk Measure is Proportional to:[b]	Correction Factor (CF) for modifying IRIS Risk Measures:[c]
Slope Factor [per mg/(kg/day)]	$(W^S)^{1/3} = (70)^{1/3}$	$(W^P/70)^{1/3}$
Water Unit Risk [per µg/l]	$I_W{}^S/[(W^S)^{2/3}] = 2/[(70)^{2/3}]$	$(I_W{}^P)/2 \times [70/(W^P)]^{2/3}$
Air Unit Risk: A. Particles or aerosols [per µg/m^3], air concentration by weight	$I_A{}^S/[(W^S)^{2/3}] = 20/[(70)^{2/3}]$	$(I_A{}^P)/20 \times [70/(W^P)]^{2/3}$
Air Unit Risk: B. Gases [per parts per million], air concentration by volume,	No explicit proportionality to body weight or air intake is assumed.	1.0 Ppm by volume is assumed to be the effective dose in both animals and humans.

[a] W = Body weight (kg)
I_W = Drinking water intake (liters per day)
I_A = Air intake (cubic meters per day)

[b] W^S, $I_W{}^S$, $I_A{}^S$ denote standard parameters assumed by IRIS

[c] Modified risk measure = (CF) x IRIS value
W^P, $I_W{}^P$, $I_A{}^P$ denote non-standard parameters of the actual population

As one example of the use of Table 1A-1, the recommended value for the average consumption of tap water for adults in the U. S. population derived in this document (Chapter 3), is 1.4 liters per day. The drinking water unit risk

for dichlorvos, as given in the IRIS information data base is 8.3 x 10^{-6} per µg/l, and was calculated from the slope factor assuming the standard intake, I_W^S, of 2 liters per day. For the United States population drinking 1.4 liters of tap water per day the corrected drinking water unit risk should be 8.3 x 10^{-6} x (1.4/2) = 5.8 x 10^{-6} per μg/l. The risk to the average individual is then estimated by multiplying this by the average concentration in units of μg/l.

Another example is when the risk for women drinking water contaminated with dichlorvos is to be estimated. If the women have an average body weight of 60 kg, the correction factor for the drinking water unit risk is (disregarding the correction discussed in the above paragraph), from Table 1A-1, is $(70/60)^{2/3}$ = 1.11. Here the ratio of 70 to 60 is raised to the power of 2/3. The corrected water unit risk for dichlorvos is 8.3 x 10^{-6} x 1.11 = 9.2 x 10^{-6} per μg/l. As before, the risk to the average individual is estimated by multiplying this by the water concentration.

When human data are used to derive the risk measure, there is a large variation in the different data sets encountered in IRIS, so no generalizations can be made about global corrections. However, the typical default exposure values used for the air intake of an air pollutant over an occupational lifetime are: air intake is 10 m^3/day for an 8-hour shift, 240 days per year with 40 years on the job. If there is continuous exposure to an ambient air pollutant, the lifetime dose is usually calculated assuming a 70-year lifetime.

3. CORRECTIONS FOR INTAKE DATA

When the body weight, W^P, of the population of interest differs from the body weight, W^E, of the population from which the exposure values in this handbook were derived, the following model furnishes a reasonable basis for estimating the intake of food and air (and probably water also) in the population of interest. Such a model is needed in the absence of data on the dependency of intake on body size. This occurs for inhalation data, where the intake data is not normalized to body weight, whereas the model is not needed for food and tap water intakes if they are given in units of intake per kg body weight.

The model is based on the dependency of metabolic oxygen consumption on body size. Oxygen consumption is directly related to food (calorie) consumption and air intake and indirectly to water intake. For mammals of a wide range of species sizes *(Prosser and Brown, 1961)*, and also for individuals of various sizes within a species, the oxygen consumption and calorie (food) intake varies as the body weight raised to a power between 0.65 and 0.75. A value of 0.667 = 2/3 has been used *in EPA* as the default value for adjusting cross-species intakes, and the same factor has been used for intra-species intake adjustments.

[NOTE: Following discussions by an interagency task force *(Federal Register, 1992)*, the agreement was that a more accurate and defensible default value would be to choose the power to 3/4 rather than 2/3. This will be the standard value to be used in future assessments, and all equations in this Appendix will be modified in future risk assessments. However, because risk assessors now use the current IRIS information, this discussion is presented with the previous default assumption of 2/3].

With this model, the relation between the daily air intake in the population of interest, $I_A^P = (m^3/day)^P$, and the intake in the population described in this handbook, $I_A^E = (m^3/day)^E$ is:

$$I_A^P = I_A^E \times (W^P/W^E)^{2/3}.$$

4. CALCULATION OF RISKS FOR AIR CONTAMINANTS

The risk is calculated by multiplying the IRIS air unit risk, corrected as described in Table 1A-1, by the air concentration. But since the correction factor involves the intake in the population of interest (I_A^P), that quantity must be included in the equation, as follows:

$$
\begin{aligned}
(\text{Risk})^P &= (\text{air unit risk})^P \times (\text{air concentration}) \\
&= (\text{air unit risk})^S \times (I_A{}^P/20) \times (70/W^P)^{2/3} \times (\text{air concentration}) \\
&= (\text{air unit risk})^S \times [(I_A{}^E \times (W^P/W^E)^{2/3}/20)] \times (70/W^P)^{2/3} \times (\text{air concentration}) \\
&= (\text{air unit risk})^S \times (I_A{}^E/20) \times (70/W^E)^{2/3} \times (\text{air concentration})
\end{aligned}
$$

In this equation the air unit risk from the IRIS data base $(\text{air unit risk})^S$, the air intake data in the Handbook for the populations where it is available ($I_A{}^E$) and the body weight of that population (W^E) are included along with the standard IRIS values of the air intake (20 m^3/day) and body weight (70kg).

For food ingestion and tap water intake, the intake values are empirically normalized to body weight and therefore the intake data do not have to be corrected as in section 3 above. In these cases corrections to the dose-response parameters in Table 1A-1 are sufficient.

5. REFERENCES

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